LCA Methodology

Procedures and Tools for Generating and Selecting Alternatives in LCA

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Abstract

Life Cycle Assessments (LCAs) frequently do not contribute to sustainable development because product alternatives with a truly low environmental burden are not included in the assessment. As a result, environmentally-friendly alternatives are not uncovered, although much effort has been put into collecting inventory data and making an impact assessment. Part of this problem is caused by the defensive use of LCAs. Companies eager to show that their product is not too bad for the environment prefer to compare their product with alternatives that are not very promising in an environmental sense. To (mis)use LCAs in this way is quite easy, because the LCA methodology and handbooks provide few guidelines and little advice on how to generate and select adequate alternatives. An analysis of the problems related to the alternatives is given using insights drawn from the field of policy analysis – a field in which methodological rules for the generation of alternatives in policy studies have been developed – ecodesign and the LCA discipline, and measures to reduce the problems are developed. Explicating the different steps in the determination of alternatives in the goal and scope formulation stage of an LCA process, and the development of a toolbox for this activity, would certainly improve the quality of the selection of alternatives. Furthermore, involving stakeholders and a group of experts in the generation and selection process will increase the variety and relevance of alternatives, and the social support for alternatives.

Keywords: Alternatives in LCA; goal definition; guidelines; social support; stakeholder participation; sustainability; factor 20; toolbox

1 Problems with Alternatives

The various actors involved in projects that might impact on the environment have become increasingly aware of the need for sustainable development and it is now an important issue.

Present patterns of production and consumption cannot be sustained in a world with a growing population, rising human aspirations and limited carrying capacity. The use of products with a relatively low environmental burden is an important step towards a more sustainable society. LCAs are used to distinguish products with a high environmental burden from those with a low environmental burden. It is hoped that the use of LCAs supports a shift towards environmentally-friendly products. In practice, this role of LCAs is hampered by the fact that the alternatives studied are not carefully selected. A number of extreme examples are shown below of studies that were not peer reviewed.

Ecotax on mineral water bottles. In Belgium, the Minister of Environmental Affairs was considering an ecotax on mineral water bottles made from PVC because it was generally thought that these bottles had a large environmental burden. PVC, glass and PET bottles were compared (De Baere et al. 1994) and the chemical industry concluded that an ecotax was not justified because the environmental burden of PVC bottles and the other bottles were equal. Greenpeace, however, did not accept this conclusion, because PVC was not compared with environmentally promising alternatives such as recycled PET bottles (Bras-Klapwijk 1999). The researchers explained that they had only selected commercially available alternatives, while recycled PET bottles were not available on the Belgium market.

Disposable or reusable cups? Researchers compared plastic and porcelain alternatives. They concluded that plastic alternatives were better for the environment when porcelain cups were used only once before being washed. The environmental movement rejected the conclusion that disposable plastic cups were better for the environment. One of their key arguments was that the study compared a plastic cup with a porcelain cup and saucer, a luxury item when compared to a mug, and consequently a choice that favors the plastic alternative (De Groot et al. 1993, Herberigs 1993).

The examples given show two interrelated problems.

- Alternatives with an assumedly low environmental burden were not included in the LCA
- Stakeholders rejected the results of the LCA study because important alternatives were left out.

As a result, LCAs may not always provide policy-makers and others with the unbiased facts required to make our society more sustainable. Furthermore, study results are not seen as authoritative, which hampers the policy-making process as possible alternatives are not discussed in a constructive way.

The poor quality of alternatives is caused by the defensive attitude of companies, and also because the activity of generating and selecting alternatives is hardly discussed and structured in the LCA methodology and handbooks. Tools for this activity have not been developed, probably because it is not seen as a scientific activity. Last but not least, ISO 14040 requires many items that have to be described in the scope of the study, but it does not require a description of, or argumentation for, the alternatives that have been selected, nor of those that remain outside the assessment. In ISO 14041, with regard to goal and scope definition, only the requirements for the description of the function and the functional unit are provided. This – as I will argue later – is only a part of the whole step of generation of alternatives.

The selection of adequate, legitimated alternatives is crucial for the success of an LCA. By legitimated alternatives I mean alternatives that are agreed upon by the different actors with a stake in the policymaking process. This article starts with a description of LCA's methodological rules such as the functional units that are helpful when determining adequate alternatives. Next, a number of additional rules are developed and a number of tools are provided that may become part of the LCA-practitioner's toolbox. The application of methodological rules, however, is not generally considered to be sufficient to obtain legitimized results. As has been argued before (Guinée 2002, Bras-Klapwijk 1999), the participation of stakeholders is essential for achieving a legitimized and relevant selection of alternatives. Involvement of stakeholders in the generation and selection of alternatives, peer reviewing the choice of alternatives and transparent reports are all of equal importance. In this paper, I pay close attention to these aspects.

2 LCA Principles

The LCA methodology advises users to determine alternatives either at the start of the study, at the goal and scope definition stage (Heijungs et al. 1992, Guinée et al. 2002) and, in some cases, also in the interpretation stage of the study. In the latter case, the information obtained on the environmental impacts of the products under study is used to develop options to reduce the environmental burden of the products or to develop better product alternatives (Graedel 2000).

The concept of a functional unit, in which the function of the product is described and which usually contains an amount or time-indication, is one of the key concepts in LCA methodology as it helps us to determine which products can be compared in a sensible way and will therefore influence the solution space. A solution space, a commonly used term in the area of policy analysis and also used by Weidema et al. (2000), is an area in which adequate alternatives can be found. Its boundaries are defined by the criteria that have to be fulfilled by the alternatives and at least part of these criteria must be mentioned in the functional unit. Only alternatives that meet the requirements given in the functional unit should be included in the study according to LCA handbooks (Heijungs et al. 1992). The choice of the functional unit and of the alternatives should be motivated, and researchers should report especially on products that are not included while they meet the requirements of the functional unit or almost meet these.

Radical changes in our production and consumption processes are needed for sustainable development. It has been advocated that we should improve our environmental efficiency with at least a factor of 4 (Von Weizsacker et al. 1997), or as others argue in the long term at least a factor of 10 (Factor 10 Club) or even a factor of 20 (Weaver et al. 2000). However, the definition of the functional unit may restrict the solution area in an LCA to alternatives that differ only incrementally in the way they fulfill a function. For example, in a study about detergents, one may use the following functional unit 'Solid or liquid detergents to clean 100 kg of laundry, furthermore the colors of the laundry should not fade'. The term detergents in the functional unit implies that a water-based washing machine is used to clean the laundry. As a result, a study will be focused on finding the most environmentally-friendly detergent, and will ignore other strategies to reduce the environmental burden of washing processes such as new techniques to clean laundry to reduce water consumption and waste water, and changes in consumer behavior to reduce the amount of laundry to be done may well not be taken into account. A broad functional unit is needed to focus on these more radical changes that may even require an innovation of the whole production and consumption system, e.g. "having clean clothes for one person during one year" (Bras and Knot 2001). The solution space of this functional unit will include all the above-mentioned alternatives.

Consensus on the sequence of the activities of defining the functional unit and determining the alternatives does not yet exist in the LCA literature. Most LCA guidelines advise one to start with defining the functional unit and to use this definition to determine the product alternatives (Guinée, forthcoming). Weidema et al. advise you to work the other way around: determine the alternatives before one defines the functional unit. The advantage of this sequence is discussed later.

The Danish Environmental Protection Agency has recently developed additional concepts for the determination of alternatives (Weidema et al. 2001). Each product has a variety of properties. Some of them are considered to be obligatory, while others are not, for the LCA. Obligatory properties are those properties that a product must have to be considered as a relevant alternative and these together form the boundary conditions of the solution space. This concept makes the generation and selection process more transparent as the definition of the functional unit usually does not contain all the relevant criteria and it will become very long and complicated. Weidema et al. distinguish the time horizon of an alternative as an important axis of the solution space. When the time horizon is short, incremental changes are frequently only possible; in the long-term, radically different products such as a zeppelin being used for freight transport are feasible, thus indicating that a market segment is also seen to be important in defining the type of alternatives that may replace an existing product. The concept of obligatory properties, time horizon and market segment all help to clarify the boundaries of the solution space.

The LCA handbook of Heijungs et al. (1992) and the manual commissioned by the Danish EPA by Weidema both leave many questions unanswered that an LCA practitioner has to deal with. How can we generate a list of alternatives? What is the role of the functional unit in the generation and selection of alternatives? How can we prevent important alternatives from being overlooked? What is there to do in cases where there are too many alternatives to be studied in detail? How can we prevent people from rejecting the outcomes of a study because they do not agree with the selected alternatives? The remainder of the article is designed to provide support for these issues.

3 Stakeholder Participation

LCAs are usually made to provide information for and to support a policy making process. The distinction between internal and external use is considered to be an important dimension. Internal use means that the LCA will only be used inside the organization of the commissioner. External use implies that the results of LCA studies are communicated to other stakeholders such as clients, governmental organizations, consumers, companies and their branch organizations, environmental organizations, and researchers. When an LCA is used externally, the study has a much larger audience and it is important that as many parties as possible are satisfied with the selected alternatives. The audience of an internal LCA is much smaller, but a careful selection of promising alternatives is important to discover interesting alternatives.

Many stakeholders will be involved in the use of external LCAs, and they will have different opinions as to what makes a suitable alternative. Stakeholders will fill in the obligatory properties for a product differently, those who want to achieve a sustainable future will be more willing to accept sustainable alternatives that have certain disadvantages such as higher cost and less comfort. Other stakeholders will not only want to achieve a lower environmental burden, but will want to search for products with new qualities and the alternatives will have to fulfill more criteria. In LCA terms, stakeholders will have different visions on what constitutes the definitive functional unit, especially regarding quality criteria and other boundary conditions.

The participation of stakeholders in the whole study process is recommended in 'Life Cycle Assessment: An Operational Guide to the ISO Standards' (Guinée et al. 2002) for external LCAs and especially when many stakeholders with diverging interests are involved in the use of the results and when these results have large consequences for one or more of these stakeholders. It is important to obtain insight into the opinions of the different stakeholders regarding the solution space and alternatives. This can be done in several ways. A steering group made up of members drawn from different stakeholder groups can be set up to discuss the alternatives which fit in with the approach described in paragraph 7.3.3 of the ISO 14040 standard. A researcher could also be invited to collect documents from different stakeholders or to interview them to get an overview of the different alternatives. Another option is to organize a brainstorming workshop with various stakeholder participants on the alternatives. To improve the quality of the brainstorming, one can also involve people who can be expected to be creative, e.g. industrial designers, or people who look at the issue from a totally different angle, e.g. advocates of a different technology.

4 Problem Formulation

Both the CML guide (Heijungs et al. 1992, Guinée et al. 2001) and Weidema (2001) mention the determination of product alternatives as an explicit step in the goal definition, but this step can be made more concrete and this will improve the quality and transparency of this process.

Policy analysts have developed a general model for the assessment of policy options, which can be used to structure the process of determining alternatives in LCA and make it more concrete. This process model is shown in **Fig. 1** where the step 'identifying, designing and screening alternatives' is shown as a second step in the assessment of alternatives. Before determining alternatives can take place, analysts must formulate the problem and they also define boundaries and constraints, in other words the analysts must define the solution space.

Policy analysts have further split up the first two steps in the process model for assessing alternatives into the following activities (Walker 1988):

- formulating the problem
- generating alternatives
- combining alternatives
- screening and selecting alternatives

These steps are commonly conducted in an iterative way, which is indicated by the dotted arrows in Fig. 1. When stakeholders find it difficult to specify the problems and goals they want to achieve, they might instead start with the generation of alternatives and use this to explicate the goals they want to achieve, e.g. by using a goals-means tree. These four activities are used to operationalize the goal and scope definition of the LCA with respect to the generation of alternatives. The first step is described below.

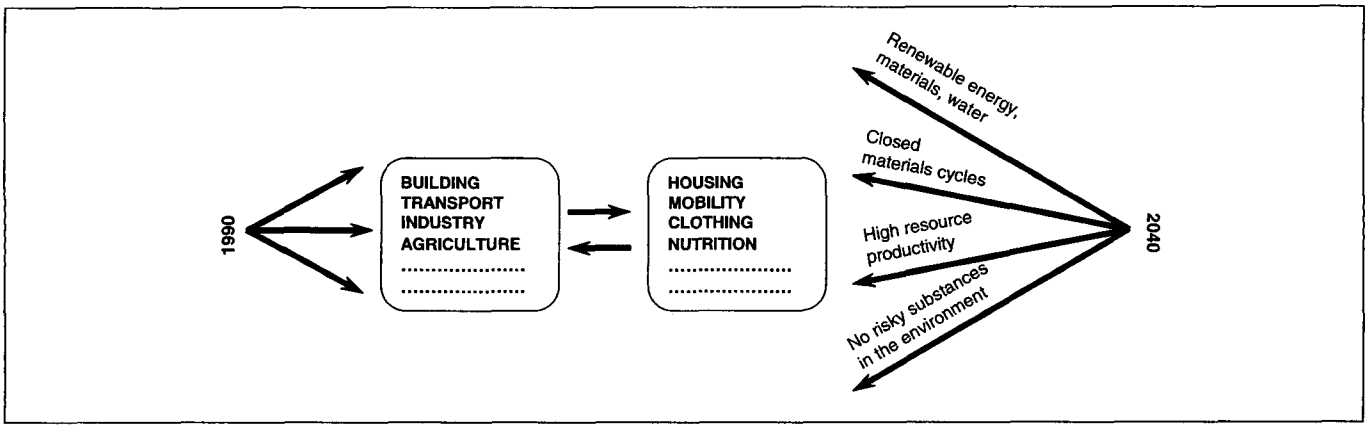

Fig. 1: Steps to analyze different policy alternatives. Source: Findeisen and Quade 1985

4.1 Formulating the problem

The various problems of the current situation are clarified in the problem formulation. The main reason to conduct this step is that the choice of alternatives to be studied will depend on the problems one wants to solve. For example, when the problem formulation makes it clear that current washing machines, detergents and procedures require too much energy and scarce resources and that detergents contain toxic substances, so that one should look for alternatives that avoid these problems as much as possible. The structure problem definition / alternative generation can be recognized in the way in which an LCA is used:

- In the field of EcoDesign, one starts quite often with an LCA or a more qualitative environmental assessment of the existing product, and uses this information to redesign the product or to develop completely different products (Brezet and Van Hemel 1997).
- Recommendations for new alternatives or other improvements in the interpretation stage are preceded by an impact assessment of one or more products.

Yet, the activity of identification of environmental problems or goals is not explicitly defined in the goal and scope definition. This hampers a successful determination of alternatives in the LCA. Therefore, it is proposed that each LCA be started with a problem formulation activity. This idea is not new and was proposed in 1991 in a study from McKinsey in which an LCA management methodology was developed (VNCI 1991).

The problem formulation should also focus on goals and desirable futures. This makes the assessment more pro active and is especially valuable for strategic assessments that include alternatives with a longer time horizon. The backcasting methodology developed by the Dutch Sustainable Technology Development (STD) program is one way to focus on desirable futures and to search for more radical changes (Weaver et al. 2000, Van Heel and Jansen 1999). The program focuses on the development of sustainable technology that will reduce the environmental burden with a factor of 20 to arrive at the far reaching changes that are needed for a sustainable future. The process starts with a strategic problem orientation. Next, a vision for a desirable future is developed. The future vision for the food sector, for example, contained five main alternative innovation tracks: sustainable multifunctional land use, high-technology closed-cycle horticulture, integral crop/biomass conversion, novel protein foods and sensor technology. Such a vision is used to define near-term actions that will be needed to realize the future vision. This activity is called backcasting (**Fig. 2**).

An integral description of problems and desirable futures that includes environmental, economical, social, consumer aspects can be used to generate alternatives that focus on all these problems and desires. For example, it may be pointed out that current clothes washing processes are unsustainable and expensive, or that households may feel that the washing process takes too much time. Philips Consumer Electronics checks its new product-concepts on their environmental merit, and on their advantages for the company, with the potential consumer and society, because this increases the chance of a successful implementation of sustainable alternatives. This approach is also advocated by the Produktlienanalyse (PLA) methodology developed in Germany: products have to fulfill ecological, economical and social criteria.

The choice between a focus on current problems and a focus on desirable futures will depend on the goal of the LCA, if one wants to identify options that are meant to optimize the current product or if one wants to identify options that may have a radical nature for the next 10 or 20 years. A pro-active approach focusing on desirable futures does not make sense when a company wants to optimize a product without any new investments. However, when a new product is designed or when a government is going to take a far reaching decision, it is sensible to work with goals and desirable futures.

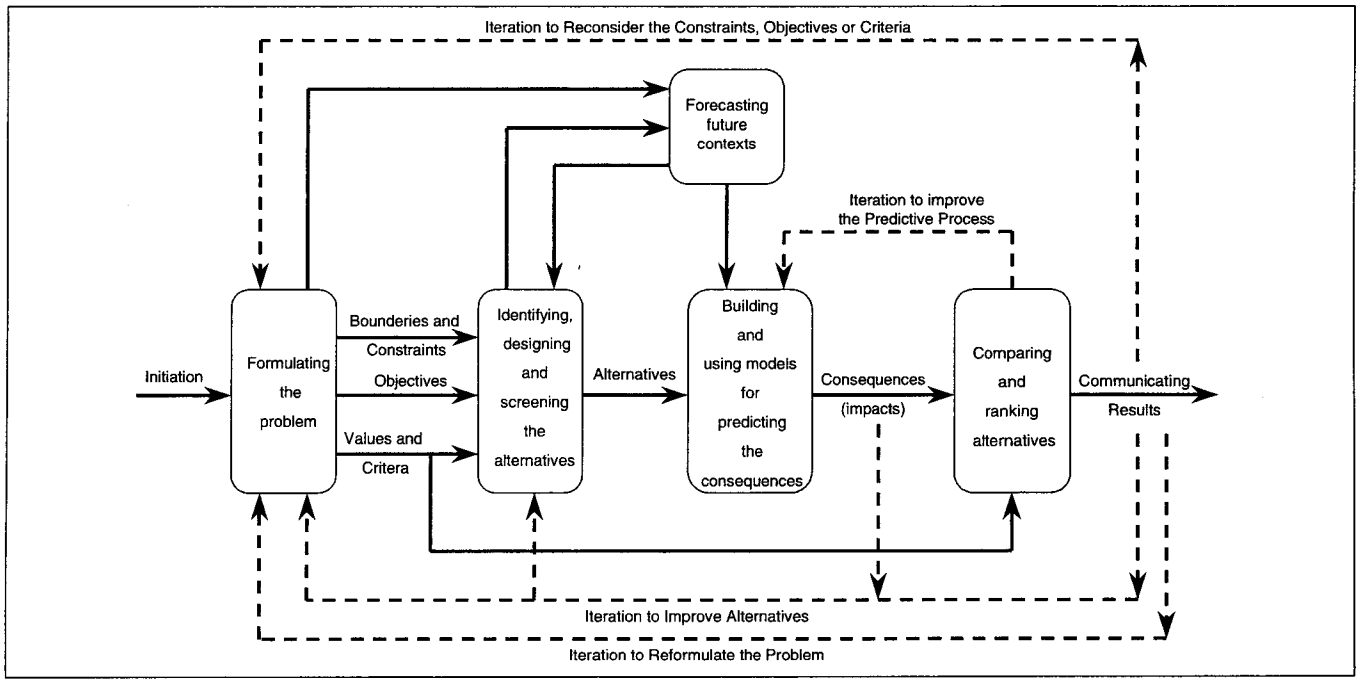

Fig. 2: Backcasting: towards sustainable technology. Source: Weaver et al. p. 75

Concluding, it is recommended to pay attention to the problem formulation in the goal and scope definition of an LCA in order to generate more adequate and relevant alternatives. This means that the client, stakeholders and LCA practitioners define environmental and other problems of the current situation and/or identify desirable futures before the generation of alternatives takes place.

5 Generating Alternatives

The next activity is to generate alternatives. Policy analysts find it important to generate a wide range of alternatives for consideration (Walker 1988: 220). If an alternative is not included in the goal definition, it will probably never be examined. Furthermore, the study may be criticized afterwards by the stakeholders when certain alternatives are missing, as the example of the plastic versus porcelain cups and saucers shows.

In an LCA, one can include products, technologies and other alternatives that are already in use or on 'the shelf', although one cannot limit oneself to the existing alternatives in order to achieve sustainability. As Enthoven (1975; 436 in Walker 1988) remarked, 'A design of a good new alternative is likely to be worth a lot more than a thorough evaluation of some unsatisfactory old alternatives'. It is thus very important to put time and energy into designing new alternatives.

Thus, two different generation processes exist, that supplement each other: *search* and *design* (cp. Alexander 1979, 1982; in Walker 1988). The search approach can be used for alternatives that are available and only need to be identified by the analyst. The design approach can be used for alternatives that are unique and have not been proposed previously.

The generation of alternatives should have a brainstorming nature, in other words everybody should get a chance to bring in his or her ideas and judgments, an evaluation of the value of the alternatives should be postponed to a later stage. The functional unit, the obligatory criteria, the time horizon and the market segment can be used to direct the generation of alternatives, because they show the boundaries and constraints of the solution space. However, a full definition of the functional unit conflicts with the unrestricted approach needed to generate a large variety of alternatives in most cases. The functional unit and the obligatory criteria may restrict the participants too much during the brainstorm. Furthermore, it may often happen that participants do not fully achieve consensus on all the constraints and quality criteria. For this reason, it is advised to use only the problem definition (or goals and desires), and a definition of the function that should be fulfilled to guide the brainstorming, and to abstain from a precise functional unit and other obligatory criteria at this point in time.

The LCA methodology contains many 'tools' for various parts of the life cycle assessment, such as the allocation procedures and the various evaluation methods, but the generation of alternatives is often an intuitive process. The development of a toolbox to support the generation of a large and varied amount of alternatives could improve the quality of the generation of alternatives, as such tools can be used to provide inspiration and structure.

In the Dutch Sustainable Technology Program, information on existing alternatives was found by reviewing documents of policy-makers, industry and interest groups in this area, consultations with policy-makers and consultations with experts in product design, new technologies, etc. Furthermore, case studies were conducted in other countries to get an insight in possible solutions. For example, comparing the low water use of Belgium inhabitants (58 m^3/year) to the high water use of Norwegians (196 m^3/year) and explaining the differences will give insight into possible solutions (DTO 1997: 17).

The engineering and design disciplines are especially familiar with designing. Various tools for sustainable product design have been developed. The industrial designers Brezet and Van Hemel (1997) and Van Hemel (1998) list eight 'Design for the Environment' strategies.

1. Selection of low-impact materials: clean materials, renewable materials, low energy content materials, and recycled materials.
2. Reduction of material usage: reduction in weight, and reduction in volume.
3. Optimization of product system: clean production techniques, fewer production steps, low/clean energy consumption, less production waste and few/clean consumables.
4. Optimization of distribution system: less/clean/reusable packaging, energy-efficient distribution mode, energy-efficient logistics.
5. Reduction of impact during use: low energy consumption, clean energy source, few consumables needed, clean consumables, no waste of energy/consumables.
6. Optimization of initial lifetime: high reliability and durability, easy maintenance and repair, modular/adaptable product structure, classic design, strong product-user relation.
7. Optimization of end-of-life system: reuse of product, remanufacturing/refurbishing, recycling of materials, safe incineration (energy recovery), safe disposal of product remains
8. New concept development: dematerialization, shared product use, integration of functions, functional optimization.

This ecodesign list can be used to check if one has thought of all the different ways to improve the product. New function development is especially far reaching and fits only in strategic LCAs.

Another tool to structure and inspire the brainstorming process has been developed by McKinsey (VNCI 1991). They propose using a flow diagram showing the processes, emissions and resources in the product-chain. The flow diagram contains a number of 'taps' that form a point of attack to reduce the environmental burden of the product system. For example, the tap 'products' inspire the development of solutions for reducing the quantity of products used.

For most of us, the word design points to technical objects. However, it is also possible to design social strategies, for example a television program that will influence consumer behavior. Furthermore, as Cramer and Zegsveld (1991) argue, cleaner technology will bring us nowhere when the technology changes are not accompanied by social changes. The SusHouse project focused on the development of system innovations in which technological and social aspects of a product and consumption system change in interaction, see Quist et al. (2001) and Bras-Klapwijk et al. (forthcoming) for a description of the methodology used to design these system changes.

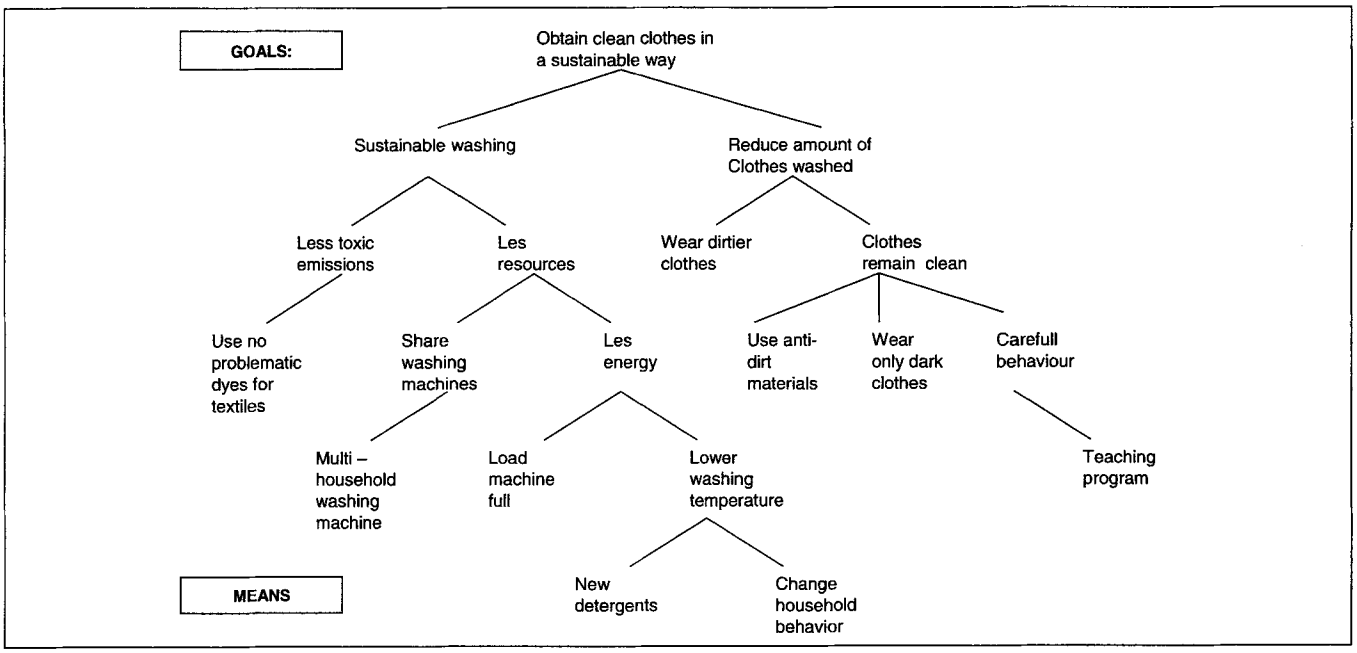

Fig. 3: Goals-Means tree for washing clothes

The tools described above focus specifically on the design of sustainable alternatives. The goals-means tree is a general tool taken from the field of policy analysis that may become part of the toolbox of the goal and scope definition. Goals are shown at the top of the tree, e.g. decreasing the use of energy, decreasing the use of scarce resources, increasing the lifetime of the washing machine (**Fig. 3**). Concrete alternatives that can be used to attain these goals are shown at the bottom of the tree: preventing over-dosing with detergents by the consumer, using lower washing temperatures, increasing the load capacity of the washing machine, using lower-load washing machines (2.5 kilos of clothes instead of five kilos), using multi-house hold machines. It is even possible to become more concrete: detergent overdosing can be prevented by information campaigns and improving the design of measuring spoons. The tree can be used to focus brainstorming activities, to check the completeness of the brainstorming results, or to structure brainstorming results.

Often, the alternatives generated in the brainstorming process are combined into strategies. A strategy is a combination of options, a set of actions to meet a sustainable product-system. This topic is not discussed further here.

6 Screening and Selecting Alternatives

Numerous alternatives and combinations of alternatives can be generated in an LCA study process. So many, in fact, that analyzing and evaluating all the alternatives is impossible within a reasonable time and within resource constraints. In addition, some are not sufficiently different to warrant separate treatment or some are probably poor in environmental performance and other aspects.

Different criteria can be applied to select valuable alternatives and sets of alternatives. Policy analysts bound the space of promising alternatives by selecting alternatives that meet the following criteria:

- Does the alternative meet certain limitations such as the functional unit and other obligatory criteria?
- Is the alternative feasible (see Walker 1988: 229)?

This strategy eliminates sets of potential alternatives by placing constraints on the characteristics of alternatives. In LCA terms, the LCA researcher should check if the alternative meets the requirements of the functional unit. Thus, at this point, the functional unit and all the obligatory criteria need to be defined fully. However, one should not apply the definition of the functional in a very rigid way. Alternatives that are highly potential in many areas, but do not meet a requirement completely, are also valuable and are relevant alternatives that should be included in the LCA.

A second strategy proposed by the policy analyst Walker is simplified assessment. Alternatives are included when they seem:

- promising with respect to environmental criteria
- promising with respect to other criteria, e.g. acceptance by consumer, economic benefits

The basic idea is that the alternatives are screened on a number of criteria. Environmental performance and other aspects are determined in a quick and often qualitative way and the outcomes are used to select the most promising alternatives for detailed environmental impact assessment. Graedel's screening strategies (1998) can be applied or techniques listed by Tischner (2001) in the field of EcoDesign.

The VNCI manual (1991) proposes selecting alternatives that fit in with the decision space of the commissioners of the study. Other criteria can be added: representatives of the product for a larger set of products, market share, etc. These criteria were used in the Dutch packaging covenant in which parties had to decide between using reusable and one-time packaging for different products.

Walker (1988) also introduced criteria related to the whole set of alternatives. It is important that the complete set of

alternatives has sufficient variation. The idea is that it is more interesting to study completely different alternatives than rather similar ones. One may, for example, prefer to include an alternative that does not seem very promising or does not meet certain limitations for the sake of diversity, and to promote a reaction and discussion.

Furthermore, a base case should be included in the LCA, e.g. current washing machines, detergents and washing practices. By comparing the effects of other alternatives to the 'base case' or the 'do-nothing scenario', it is possible to determine if a proposed alternative will be better for the environment and how much of an improvement can be expected. In some cases, the goal of an LCA is to distinguish a number of bad alternatives from good ones. In this situation, a very sustainable alternative can be used as a base case to which the 'bad' ones are related.

7 Conclusion, Recommendation and Perspective

Defensive use of LCAs happens too often. Valuable, proactive alternatives are often not included in the assessment. The best way to achieve a legitimized and high quality set of alternatives is to organize processes in which various stakeholders are involved in the idea generation. In addition, the generation of alternatives will benefit from the following methodological improvements.

1. Generation and selection of alternatives should become an explicit part of the goal and scope formulation stage. Four activities have to be conducted: problem formulation, generating alternatives, combining alternatives into strategies, screening and selecting alternatives.
2. Problem formulation focuses on problems or on desirable futures, the latter is suitable for decisions with a larger time horizon. An integral approach towards this activity is recommended; in other words, non-environmental aspects should also be included as well, as this will lead to alternatives that are attractive from various viewpoints.
3. Generation of alternatives should have a free, brainstorming nature and yield a large variety of alternatives. Involvement of stakeholders will increase the social support for the alternatives and improve the variety of alternatives produced. Both search and design strategies can be applied. Creativity is essential. Use of a toolbox for this activity will improve the quality of the generation. The following tools may form part of this toolbox: ecodesign and other checklists, goal-means tree, chain model, document analysis, case studies, workshops and brainstorming procedures.
4. In general, not all the alternatives can be assessed and selection is needed. The following criteria may be applied: Does the alternative meet the definition of the functional unit and other limitations, is it feasible? Is it promising with respect to environmental aspects? Is it promising with respect to other criteria? Does it fit in with the decision space of the commissioner and stakeholders involved? Is it representative of a larger set of products? Furthermore, the final set should be varied and include a base case.

These recommendations will lead to a more careful and thoughtful process for determining alternatives. When we realize that the selection of alternatives has a strong influence on the scope of an LCA study, it seems reasonable to pay more attention to this activity in the ISO 14040 and 14041 standards. The relationship between design for the environment and LCA is discussed and further worked out in the TC 207 discussions on the ISO 14000 family. When the ISO standards are changed, a subparagraph on generating and selecting alternatives could be added to ISO 14040 (e.g. just before 5.1.2.1) and also to 14041 (just before 5.3.2).

Further empirical research is needed for a more mature approach to alternative selection in LCAs, and to test and improve the ideas presented in this paper.

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